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Four subjects were tested in a cockpit simulator using a secondary task to measure reserve information processing capacity under two levels of flight control and four levels of multifunction switching. Results suggest that flight control impacts both input-output and central processing stages whereas mere anticipation of switching tasks effects input-output only. Difficult flight control over

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reduced the effective information processing reserve by 54 percent on the average. The corresponding losses attributable to anticipation of multifunction switching were 20 and 31 percent for simple and complex tasks respectively. The study has implications for design of effective digital processing aids and mental workload measurement.

PREFACE

This research was conducted by the Systems Research Branch, Human Engineering Division, Aerospace Medical Research Laboratory. The research supported Project 2050, "Human Performance Design Criteria," Task 205002, "Multipurpose Display Switching," under the Digital Avionics Information System (DAIS) Advanced Development Program, and Project 7184, "Man-Machine Integration Technology" Task 718414, "Operator Workload Assessment."

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INTRODUCTION

The evolution of compact, lightweight, high-capacity digital computers has made possible the development of digital avionics information systems. Such systems promise a number of advantages to both aircraft designers and users. For example, when interfaced with multipurpose cathode ray tube displays and multifunction switches, digital computation and storage capabilities can be used to reduce the number of dedicated instruments competing for limited cockpit panel area. Information which is not required by the pilot, or other crew members, on a continuous or frequent basis can be stored and presented on demand either automatically, as related programmed mission events transpire, or in response to operator requests via manual control actions. And, of course, with reduced demands for panel space, it will be easier to locate the multipurpose controls and displays in prime reach and viewing areas.

However, experienced aircraft crew members are troubled by the prospect of possible added activity—both mental and physical—required to gain access to information which is normally present on dedicated instruments. Should the demand for such unique activities occur during times of peak operator workload, the impact on mission success might not be offset by the increased calculating power, speed, or accuracy afforded by the digitally-based systems. One of the purposes of this study was to evaluate the impact of certain multipurpose control/display task requirements on the crewman's reserve information processing capacity.

Of particular interest was the question as to whether or not the maintenance of knowledge of procedures associated with multifunction keyboard operation reduced the operator's reserve capacity for making choices, or decisions, including related memory functions such as might be required to handle contingency situations that occur during a mission. Another purpose of this study was to obtain preliminary evidence relative to the compatability of multifunction keyboard operations with concurrent continuous flight control tasks.

METHOD

APPARATUS

General. A computer-based simultor was used to simulate, present and score the task situations investigated. The simulation software is described in greater detail in a separate report (Brandt and Wartluft, 1975).

Of the three different tasks involved, two, flight control and communications/IFF switching functions, represented actual tasks in operational aircraft systems. The third was an information processing task which served as a test to measure cognitive reserve capacity under various primary task conditions. All three tasks were implemented within an aircraft cockpit fixed-base simulator (Figure 1). The simulation program involves a real-time interactive graphics system which includes processing functions for simultaneously executing three separate tasks. The program was executed on an IBM system 370 computer operating under the standard MFT version of the Operating System. IBM hardware components utilized include: IBM System/370 (Model 155) computer, three 2250-3 display units (interfaced via 2840-2 display control), 1403 printer, 2501 card reader, 2520 card punch, 3215 console printer-keyboard, 1827 data control unit (with digital and analog input/output features). The storage control unit used was an ITEL 7830 with three 7330 disk units.

Operating characteristics of the programs were as follows: a 200 millisecond (msc) update, or recurrence, interval; 26 msc computer operate time per recurrence; and 85K bytes of computer memory.

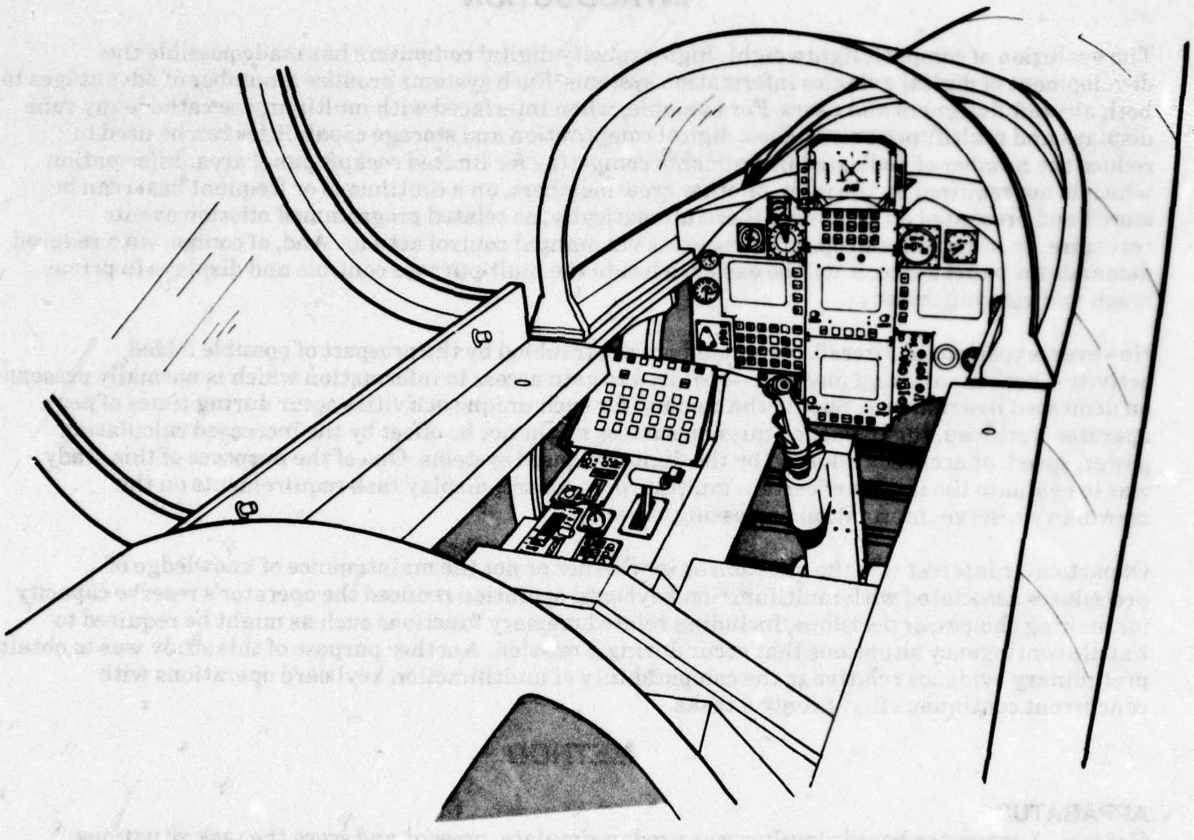


Figure 1. Aircraft Cockpit Simulator

Flight Control/Display. The front panel of the cockpit was equipped with three functional CRT-type displays. The center display was used to present information concerning basic flight parameters in a moving tape format (Figure 2). The cockpit also contained a throttle with afterburner switch (left side panel) and a center-mounted joystick control which were used, in combination with the displayed flight information, to "fly" various maneuvers. The seven different maneuvers flown, and associated "fly to" specifications, are shown in Table 1. Although lacking trim and rudder control capabilities, the simulated aircraft was programmed to respond like a high performance fighter. Flight control performance was scored automatically by the computer system. Printed outputs of simulator performance data included both mean absolute and root mean square error relative to specified control values based on "fly to" instructions for altitude, heading, bank angle, pitch, indicated airspeed, vertical velocity, angle-of-attack, and g-load.

TABLE 1

MANEUVERS AND ASSOCIATED SPEED AND G VALUES
USED TO STRUCTURE FLIGHT CONTROL TASKS

MANEUVERS	*SPEED (KNOTS)*	G
1—Straight and Level	500	1.0
2—Left Turn	500	1.5
3—Right Turn	500	1.5
4—Turning Dive (2,500 Ft/Min)	500	1.5
5—Stall	240	1.0
6—Turning Ascent	500	1.0
7—High-G-Orbit	600	3.0

Multipurpose Control/Display. Between the front instrument panel and the left side panel there was a multifunction keyboard (MFK), similar in concept to one developed for the Integrated Information Processing and Control System (Zipoy, Premselaar, Gargett, Belyea, and Hall, 1970). This MFK, in combination with the CRT on the upper left of the front cockpit panel and a numerical entry keyboard, that was also located on the front instrument panel (lower left), was used to simulate a multifunction interface with digital avionics subsystems (see Figure 3). Subsystems, functions and states were displayed on the CRT to complement the incomplete feedback afforded by back-projected legends on the MFK pushbutton faces. (The CRT display for the IFF function is illustrated in Figure 7).

The top row of springloaded pushbuttons were "dedicated" controls for use in interfacing an avionics subsystem with the multifunction control-display capability. Only the first and second buttons from the left were used in this study, and they were associated with Communications and IFF (identification-friend-or-foe), respectively. This set of switches is referred to as the first level of indenture in the MFK system.

Each pushbutton (manufactured by Industrial Electronic Engineering, Inc.) in the 4 x 6 matrix in the lower portion of the MFK unit could be programmed for as many as 12 different functions. The function at any given time was determined by the preceding pushbutton action.

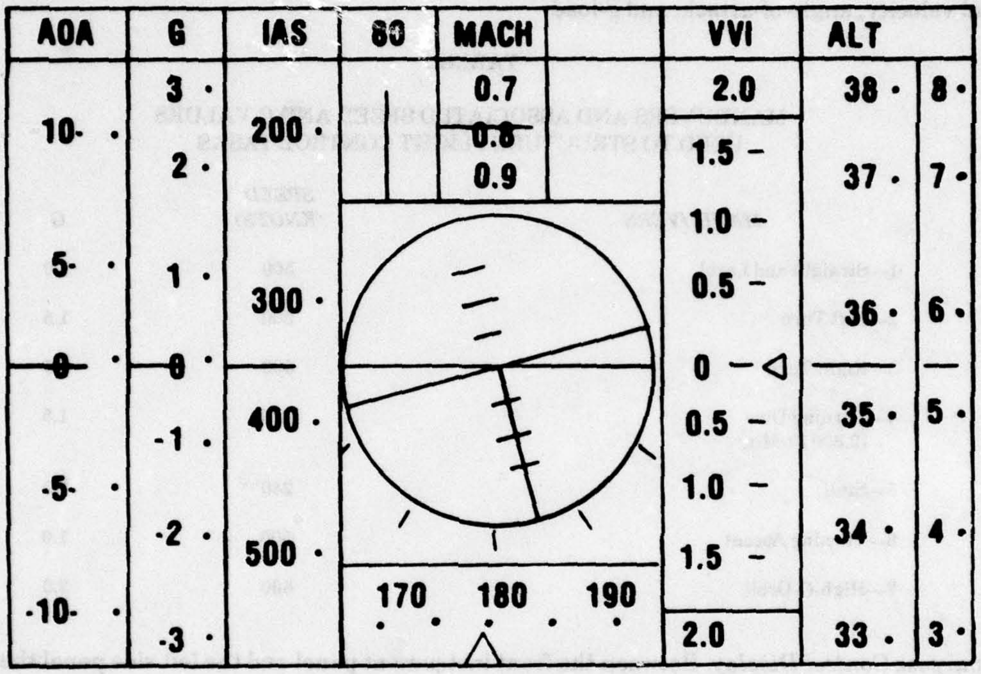
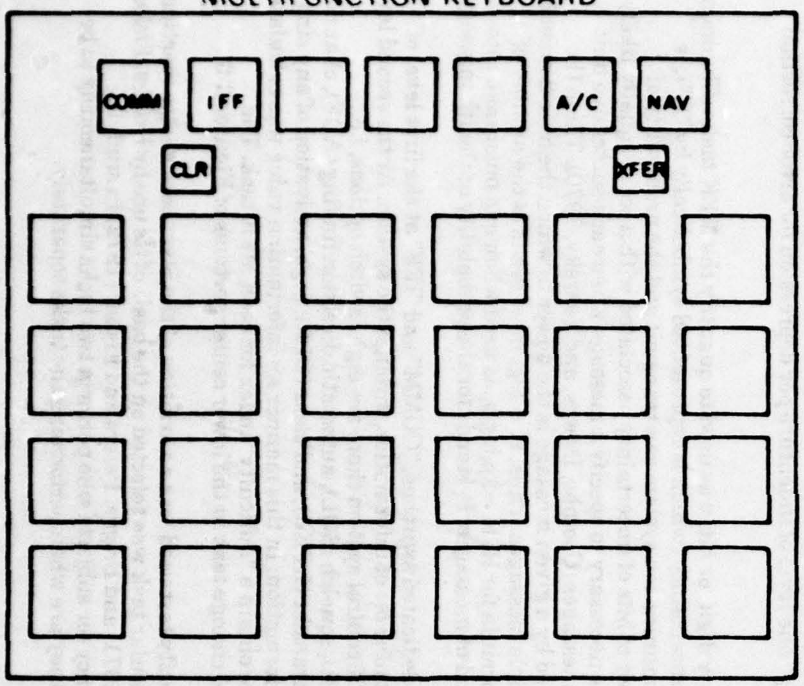


Figure 2. Flight Instrumentation Display Format (Column headings from left to right represent: angle-of-attack, g-loading, indicated airspeed, percent of peak engine revolutions-per-minute, mach value, vertical velocity, and altitude).

MULTIFUNCTION KEYBOARD



$$H_1 = \log_2 2$$

MULTI PURPOSE DISPLAY 1

SET	T	EAR	SQL	DF	CH	FREQY
INT	0	0				
UHF	0	0	0	0	20	353.60
GRD	0	0	0	0		243.00
FM	0	0	0			75.45
AUX		0	0	0	16	346.5

DIRECTOR =

MULTI PURPOSE DISPLAY 2

01	326.85	11	326.85	
02	327.3	12	328.65	UHF MAIN
03	328.65	13	359.40	
04	339.25	14	358.65	
05	340.15	15	365.30	00=MAN
06	341.20	16	386.75	357.8
07	346.70	17	335.40	
08	347.60	18	397.65	
09	352.35	19	352.65	
10	348.60	20	353.60	

Figure 3. Multifunction keyboard and associated displays in communications system mode. This illustration represents the first level of indenture of which only two switches (COMM and IFF) were active; hence, activation of either switch reduced uncertainty (H) by 1 bit (log 2).

Operation of the MFK system is illustrated in Figures 3 through 6. The task illustrated is that of changing from one preset channel (channel 20) to another (channel 12) on the main UHF set. Depressing the COMM (communication system) button, at the first level of indenture, would cause the lower array of switches to assume the functions shown in Figure 4. This represents the *second* level of indenture in the MFK system.

Note that the bottom line of the CRT, labelled "DIRECTOR," informed the operator as to what steps he had accomplished via the keyboard prior to completion of the last step in the task. Following the final step, the action effected was reflected either by the appearance of an "X" in place of an "O", or, by appropriate changes in numerical entries, in the appropriate cell of the matrix formed by the column and row headings.

Selection of one of the pushbutton options afforded by the second level of indenture automatically advanced the keyboard functions and corresponding labels to options of the *third* indenture level. For example, depression of the button labelled "CH" for "channel change" (Figure 4) changed the keyboard functions and labels to appear as shown in Figure 5.

"Main UHF" is indicated by depressing the button labelled "UHF" at indenture level 3 (Figure 5). The channel change task is then culminated by entering "12" via the numerical entry keyboard (which represents indenture level 4) as shown in Figure 6 with the corresponding effect reflected on the CRT display at the intersection of the "CH" column and "UHF" row. The frequency associated with the preset channel was also presented in the last column.

Note in Figure 6 that each of the two keyboards has a "clear" button (labeled CLR on the MFK). On the numerical entry keyboard, depression of the CLR button deleted any numbers which had not been entered via the "ENTER" button. On the MFK, depression of the "CLR" button always cleared out entries associated with an incomplete task and returned the system to the first level of indenture. This contrasts with the function of the button labelled "XFER" which allowed the user to clear the entry at the current indenture level and "back up" one level of indenture per depression for error correction purposes.

The communication theory metric, binary digit, or bit, was used to quantify the MFK tasks (Shannon, 1948). This measure of information, or uncertainty (which is represented symbolically by "H"), is based on the number of messages a communication system can transmit and the probability of occurrence for each message. The number of bits of uncertainty associated with a set of equally likely messages is equal to the number of units necessary to specify a message when each successive unit eliminates half the remaining possible messages (Coombs, Dawes, and Tversky, 1970). Then, the number of *bits* of information transmitted by a given message is the power to which the base 2 must be raised to equal the total number of possible messages. Thus, $H = \log_2 m$ where m is the number of messages possible. (The more general formula for H, $H = \sum p_i \log p_i$, is used when one must take into consideration variations in the likelihood of messages. P_i stands for the probability of the ith message).

Hence, activation of one of two possible dedicated switches, "COMM" and "IFF" at the first level of indenture in the MFK system, transmits *one bit* of information through the system. At the second level of indenture in the Communication MFK control system there are eight switch options, i.e., transmit/receive (TR), receive only (EAR), squelch (SQL), automatic direction finding (ADF), channel change (CH), frequency input (FREQ), transfer (XFER), and clear (CLR); ergo, activation of any single switch transmits three ($\log_2 8$) bits of information. In this manner an information value was calculated for each step and summed across steps to obtain a "difficulty" index for each MFK task. The calculation is illustrated for the channel change task in the lower center portions of Figures 3-6.

Reserve Capacity Test. The reserve capacity test used was a variation of the Sternberg choice reaction task (Sternberg, 1966, 1969). This particular task was selected on the basis of its use by Briggs, Fisher, Greenberg, Lyons, Peters and Shinar (1971) and Briggs, Peters and Fisher (1972) in studying divided-attention effects, i.e., the tendency for subjects who perform two tasks simultaneously to be less proficient on one (if not both) than they are when performing the tasks separately.

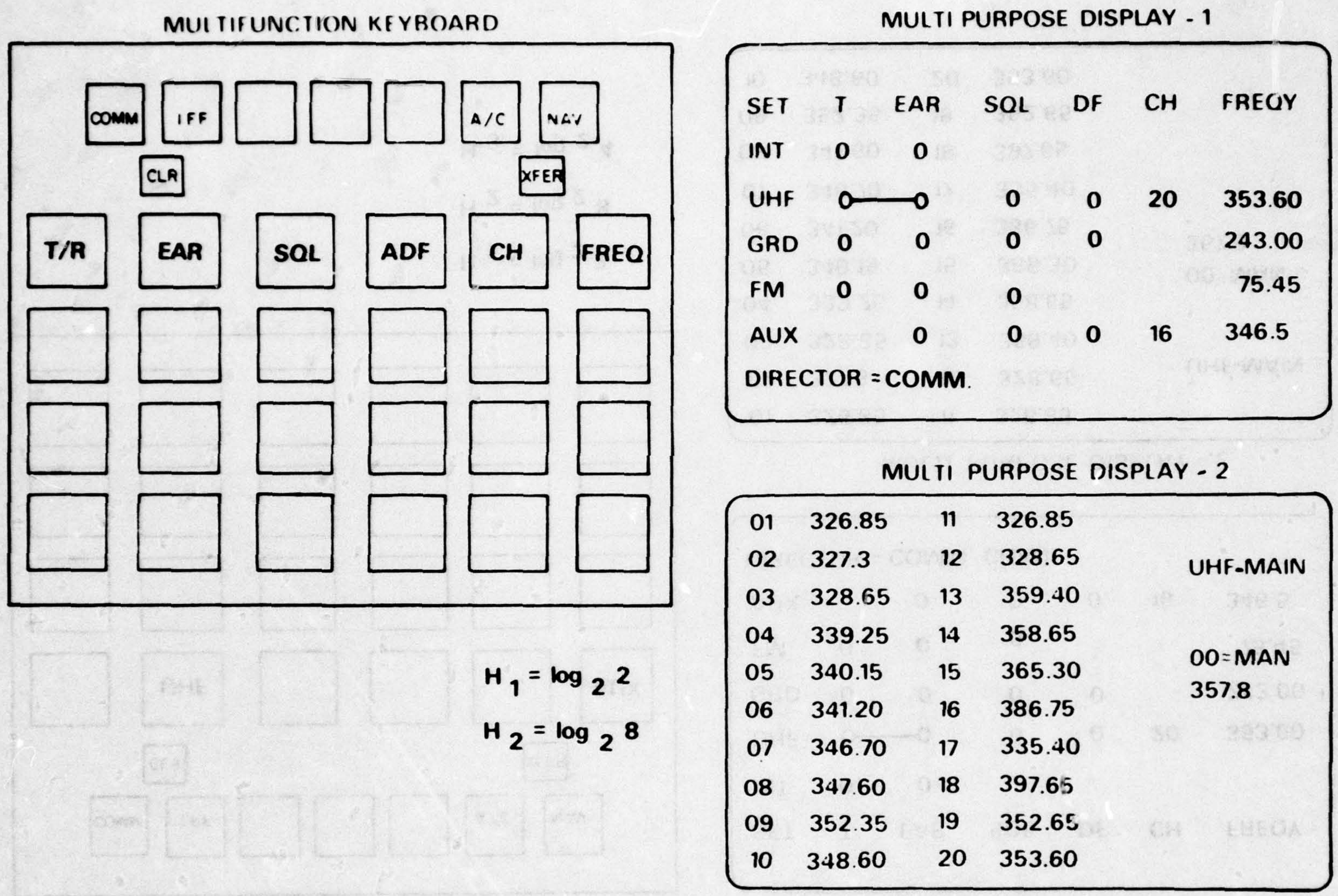
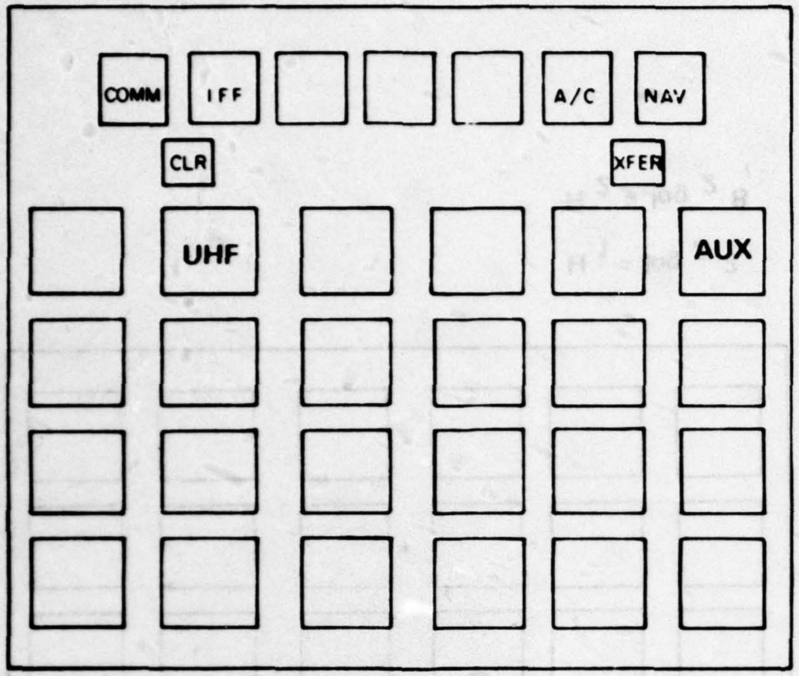


Figure 4. Multifunction keyboard and displays at level of indenture 2 with 8 active switch functions.



$H_1 = \log_2 2$

$H_2 = \log_2 8$

$H_3 = \log_2 4$

MULTI PURPOSE DISPLAY - 1

SET	T	EAR	SQL	DF	CH	FREQY
INT	0	0				
UHF	0	0	0	0	20	353.60
GRD	0	0	0	0		243.00
FM	0	0	0			75.45
AUX		0	0	0	16	346.5

DIRECTOR = COMM. CHAN.

MULTI PURPOSE DISPLAY - 2

01	326.85	11	326.85	
02	327.3	12	328.65	UHF-MAIN
03	328.65	13	359.40	
04	339.25	14	358.65	
05	340.15	15	365.30	00=MAN
06	341.20	16	386.75	357.8
07	346.70	17	335.40	
08	347.60	18	397.65	
09	352.35	19	352.65	
10	348.60	20	353.60	

Figure 5. Multifunction keyboard and displays at level of indenture 3 with four active switch functions.

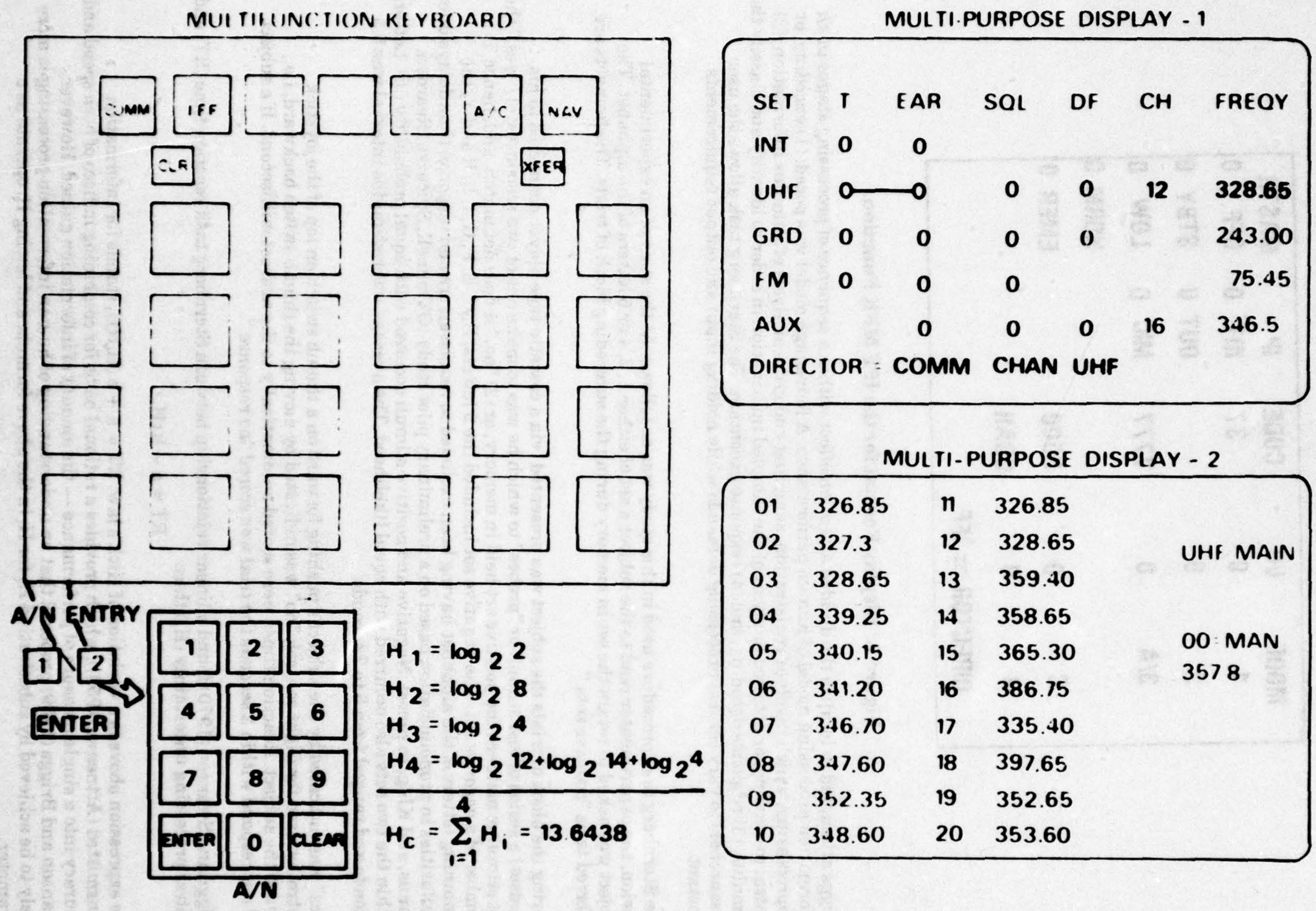


Figure 6. Multifunction keyboard and displays with numeric entry keyboard (level of indenture 4).

MODE	I/O	CODE	IP		MASTR	
1	0	37	IDT	0	OFF	0
2	0		OUT	0	STBY	0
3/A	0	7777	MIC	0	LOW	0
					NORM	0
C	0	0000			EMER	0
4	0	OBAH				
DIRECTOR = IFF						

Figure 7. Display Format for the IFF MFK Function.

Briggs attempted to localize the divided attention effect within a sequence of processing stages in an information processing model of human performance. A four-stage model was posed: (1) encoding, or preprocessing, which involves registration, sampling and gross analysis of stimulus information; (2) central processing, or detailed analysis of the sampled information in order to identify and classify the stimulus; (3) response decoding, and (4) response execution. The Sternberg task allows the user (researcher) to vary central processing demands while holding input and output requirements constant.

The Sternberg task procedure used in this study was as follows: At the start of an experimental session, the experimenter read to the subject a set of either 1, 2, 4 or 6 letters of the alphabet. The subject was asked to retain the set in memory during the succeeding block of trials. The four sets are referred to as "positive sets."

During the block of trials the subject was presented (via a cassette tape player connected to his headset) a series of test stimuli or "probes" to which he was to make one of two responses: (1) "yes," the test stimulus matches the positive set held in memory, or (2) "no," it does not match, and, hence, is a member of a *negative* set. The negative set included the 9 letters, B, C, E, F, G, I, L, R and Y, the remaining letters of the alphabet having been excluded to reduce errors and response time delays due to similarities in pronounciation based on a preliminary pilot study (O'Donnell, Spicuzza, Reardon, Pinkus, and Klug, in press). Negative and positive stimuli occurred with equal probability (.5). Letters within the two sets also occurred with equal likelihood. The average inter-stimulus interval was 5.5 seconds and ranged from 3 to 7 seconds.

"Yes" was indicated by the subject's pushing forward on a thumb switch on top of the joystick controller used for flight control; "no" was indicated by moving the thumb switch backward, i.e., toward the subject. Reaction times were scored automatically to the nearest millisecond. If a subject did not respond within 2 seconds the trial was scored "no response."

Briggs and Swanson (1970) found a linear relationship between Sternberg task reaction time (RT) and central processing uncertainty (H_c) thus:

$$RT = a + b(H_c)$$

The expression above is a variation of Hick's law: $RT = a + b(H_t)$ (H_t stands for information transmitted (Attneave, 1959)), which provides a rational basis for combining indices of both speed and accuracy into a single measure of performance — the amount of information gained. However, Swanson and Briggs (1969) proposed that an understanding of human information processing is more likely to be achieved by substituting H_c for H_t in the above formula and letting H_t operate as a parameter.

H_c is defined mathematically as $\sum_{i=1}^{m} p_i \log p_i$ where p_i represents the probability of occurrence of the ith possible outcome of central processing, and the summation is across all possible outcomes. When the task is strictly information conservation, i.e., *pure* transmission (Coombs et al, 1970), m varies directly with the number of stimuli so that $H_c = H_s$. (H_s = stimulus uncertainty). And if performance is error free in the conservation task, $H_c = H_s = H_r$, where H_r is response uncertainty.

But, in an information *reduction* task, such as the Sternberg, the above equalities do not hold. For example, when the memory set is one item, and there are nine negative set items, the probability that the positive set item will be presented as a probe cue is .5; the probability for each negative set item is approximately .055; and, consequently, H_s = 2.986 bits. By contrast, H_c = 1.0 bit, based on the fact that the probe will be the positive set item, i.e., a "match" with a probability of .5 and a negative set item, i.e., "no match," with a probability of .5. Similarly, for the two-item memory set, each positive item occurs with a probability of .25 and "no match" with a probability of .5, so that H_c = 1.5 bits whereas H_s = 3.48 bits. Because there is always a 2 choice response, H_r = 1.0 bit in each instance.

Based on the preceding rationale, the four memory sets and corresponding H_c values for this study are as follows:

	H_c *(bits)*
M-Set 1	1.00
M-Set 2	1.50
M-Set 4	2.00
M-Set 6	2.31

The equation for RT in the Sternberg task is interpreted as follows: The intercept constant, a, reflects the time required for stimulus encoding, sampling and preprocessing functions at the input stage of human information processing plus the time to decode and execute a response in the output stage; the slope, b, represents time per test to complete stimulus classification functions at the central processing stage. Therefore, if a task performed simultaneously with the Sternberg task interferes with encoding or decoding processes, its effect should be reflected by differences in intercept value, but not slope. Conversely, if the interference occurs at the central processing stage, the effect will be revealed through slope differences.

Experimenter Console and Simulator Operation. The experimenter's station and associated equipment rack are shown in Figure 8. This station was equipped with displays which duplicated those of the subject in the simulated cockpit so that the experimenter could monitor performance at all times. The experimenter communicated with the subject via microphone and headset. The rack also contained the tape players used to automatically provide instructions for MFK tasks, flight control tasks and Sternberg test stimuli. The large graphics display (IBM model 2250) in the right console panel provided the experimenter with a status display as shown in Figure 9. Note the large matrix in the lower ¾ of the display which permitted the experimenter to monitor a subject's performance on the Sternberg task through 7 blocks of trials. The column headings stand for maneuver (MAN), correct (C), incorrect (I), time-out (T-O) and total (TOT).

The simulation facility was designed to be manned by one subject (S) and one experimenter (E). After feeding the input data, specifying experimental variables for the experimental session, into the reader, the experimenter sat at the control console separated from the cockpit simulator by a portable partition. The subject sat in the seat of the cockpit simulator. Voice communications were maintained at all times by headsets worn by the E and S.

The following sequence of events summarizes operations of the simulation in the "triplex" mode:

The master control program is initiated by the E from his control console. At that point S takes control of the simulated aircraft, E informs him with respect to the MFK level (1, 2, 3 or 4) he will be working at, and also gives him the positive memory set for the Sternberg task. Then E activates a switch which causes the program to automatically turn on a cassette tape player which presents the first maneuver instruction to the S via his headset. S then "flies" the aircraft to attain appropriate values for pertinent flight parameters and pulls the trigger on his control stick. At that point an 8-track tape player is turned on and begins presenting Sternberg probe stimuli via S's headset. The data collection program then begins storing data on performance for all three tasks.

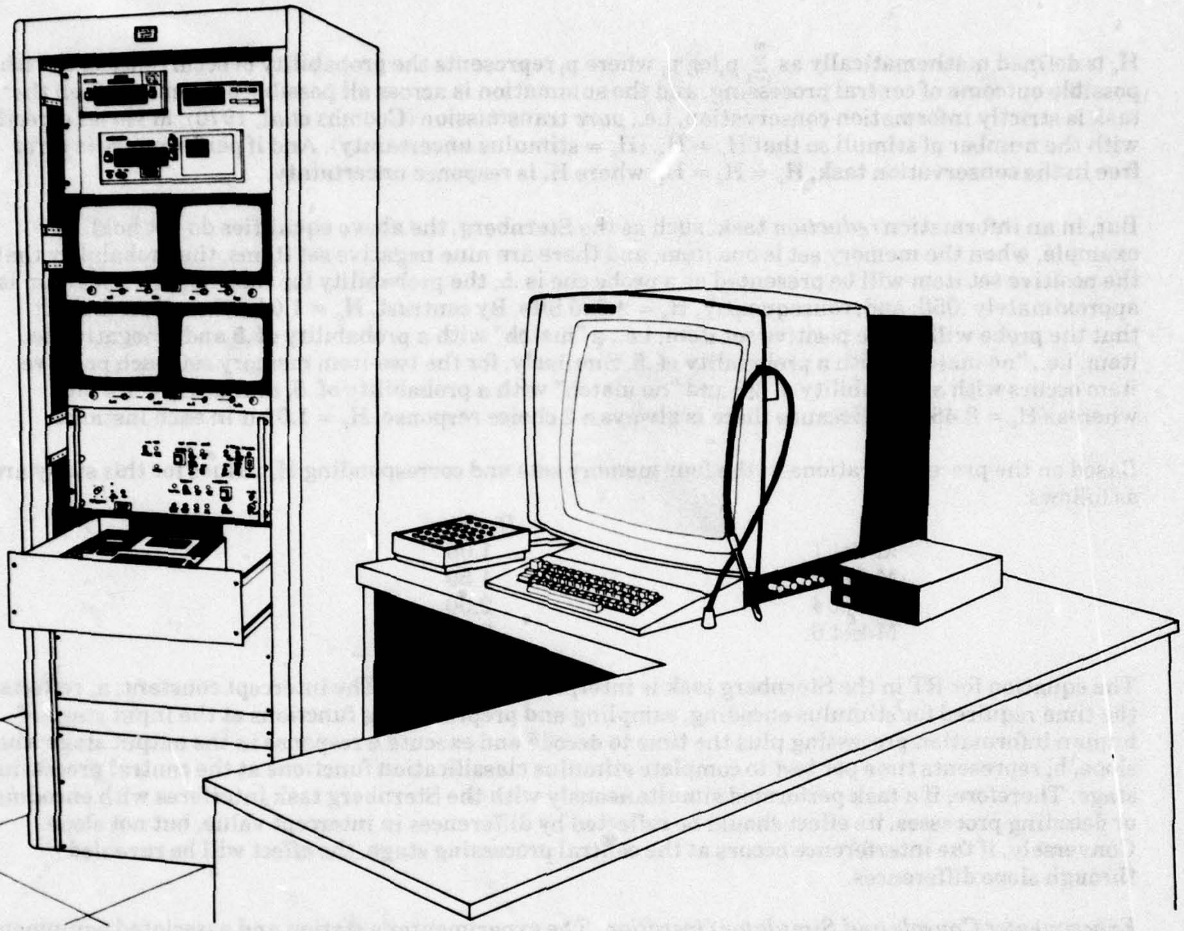


Figure 8. Experimenter's Console

EXPERIMENT ID = 751821068 SUBJECT = JOE COMPUTER

CURRENT MANEUVER NO. = 001 NO. SWITCH INSTRUCTIONS = 02

MANEUVER TYPE = 01-03 CURRENT SWITCH SEQ. NO. = 01

CURRENT M-SET = 02 CURRENT SWITCH TYPE = 002

STERNBERG	CORRECT	INCORRECT	TIME-OUTS	TOTAL
	*******	*********	*********	*****
	003	001	001	004

MAN	C	I	T-O	TOT	MAN	C	I	T-O	TOT	MAN	C	I	T-O	TOT
***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
1					4					7				
1	000	000	000	000	1	000	000	000	000	1	000	000	000	000
2	003	001	001	004	2	000	000	000	000	2	000	000	000	000
3	000	000	000	000	3	000	000	000	000	3	000	000	000	000
4	000	000	000	000	4	000	000	000	000	4	000	000	000	000
5	000	000	000	000	5	000	000	000	000	5	000	000	000	000
6	000	000	000	000	6	000	000	000	000	6	000	000	000	000
7	000	000	000	000	7	000	000	000	000	7	000	000	000	000
2					5									
1	000	000	000	000	1	000	000	000	000					
2	000	000	000	000	2	000	000	000	000					
3	000	000	000	000	3	000	000	000	000					
4	000	000	000	000	4	000	000	000	000					
5	000	000	000	000	5	000	000	000	000					
6	000	000	000	000	6	000	000	000	000					
7	000	000	000	000	7	000	000	000	000					
3					6									
1	000	000	000	000	1	000	000	000	000					
2	000	000	000	000	2	000	000	000	000					
3	000	000	000	000	3	000	000	000	000					
4	000	000	000	000	4	000	000	000	000					
5	000	000	000	000	5	000	000	000	000					
6	000	000	000	000	6	000	000	000	000					
7	000	000	000	000	7	000	000	000	000					

MESSAGE BLOCK

OPERATIONAL TASKS
****

FC	MFK	STERNBERG
**	***	*********
ON	ON	ON

Figure 9. Experimenter's Status Display

S flies the maneuver and responds to Sternberg stimuli for the prespecified interval at the end of which the cassette player provides an oral instruction over the headset calling for an MFK task. The Sternberg stimuli cease from that point until S signals, via pushbutton, end of the MFK task while continuing to fly the maneuver. The Sternberg stimuli presentation resumes, and the program "checks" to see if there are more MFK tasks to be done. If the answer is "yes," the cassette is turned on for more instructions, etc. If there are no more MFK tasks, the program checks to see if there is another maneuver to be flown; if so, the instruction is played, and the program waits for the S to signal via trigger switch on the controller that he has attained desired parametric values and is ready to proceed as indicated above. When the input data indicate that the last "maneuver" has been completed the program automatically terminates the simulation.

SUBJECTS

The experimental plan called for the use of eight subjects. However, for various reasons half the subjects were lost to attrition prior to completion of the experiment, and the program schedule precluded adequate training time for replacements. Hence, the data analysis was based on only the performance of the four subjects completing the experiment. They were paid volunteer university students, all male, with an age range of 20-24 years.

DESIGN

General. Each subject was tested under six different conditions. See Table 2. There were three single task conditions and three dual task conditions. The three single task conditions were flight control, MFK and Sternberg choice-reaction task. The three dual task conditions were flight control plus MFK, flight control plus Sternberg task and MFK plus Sternberg task. The single task conditions preceded the dual task conditions for all subjects. However, within the two conditions (single and dual task) the order of occurrence for any given subject was randomized.

INDEPENDENT AND DEPENDENT VARIABLES

Flight Control. The type of maneuver "flown" was the independent variable for the flight control task. There were seven maneuvers (Table 1). However, preliminary analyses showed that not all maneuvers were discriminable in terms of the performance measure used. As a result the maneuvers were combined into two groups labelled "easy" and "difficult." "Easy" maneuvers included straight and level flight and level turns. "Difficult" maneuvers were climbing and diving turns. Performance scores for the "high-g turn" and "stall" maneuvers were not significantly different from either group, difficult or easy, and were excluded from final analyses.

TABLE 2

EXPERIMENTAL CONDITIONS

Condition	*Independent Variables*
Single:	
(1) Flight Control	Task Difficulty — Two levels: (1) Easy: Straight and Level and Level Turns (2) Difficult: Turning Dives and Climbs
(2) Multifunction Keyboard (MFK)	Task Difficulty — Four levels: (1) I: 1-8 Bits (2) II: 9-14 Bits (3) III: 15-22 Bits (4) IV: 23-35 Bits
(3) Sternberg Task	Memory Load — Four levels: 1, 2, 4 and 6 items (letters)
Dual:	
(1) Flight Control and MFK	Same as corresponding single task conditions above
(2) Flight Control and Sternberg Task	Same as corresponding single task conditions above.
(3) MFK and Sternberg Task	Same as corresponding single task conditions above.

Flight Control task performance was measured in terms of weighted error scores as follows:

Straight and Level and Stall:

$X = (0.01)\,\Delta\,\text{altitude} + (0.1)\,\Delta\,\text{airspeed}$

Straight and Level turns:

$X = (0.01)\,\Delta\,\text{altitude} + (0.1)\,\Delta\,\text{airspeed} + (1.1)\,\Delta\,\text{g-load}$

Turning Dives and Climbs:

$X = (0.005)\,\Delta\,\text{vertical velocity} + (0.1)\,\Delta\,\text{airspeed} + (1.0)\,\Delta\,\text{g-load}$

The delta values represent average error, i.e., deviation from the prescribed "fly to" value for the given flight parameter, per unit of time on the task. Altitude was measured in feet, airspeed in knots/hour, and vertical velocity in feet/minute. The flight parameter combinations and associated weights for each maneuver type were based on pilot opinion and research findings summarized in a separate report (Woodruff, 1972).

MFK Tasks. MFK performance on multifunction keyboard tasks was measured in terms of task time and errors. These measures were combined with the task information metrics to obtain MFK information transfer rates.

Reserve Capacity Test. The principal dependent measure for the Sternberg task was reaction, or response, time. Errors and time outs (failure to respond within 2 seconds) were also recorded. Information processing rates were also derived for the various memory loads and primary task conditions investigated.

Sternberg task performance measures also served as dependent variables for indirectly assessing workload for the different levels of MFK and flight control tasks. This involved comparison of Sternberg baseline performance (obtained by administering the Sternberg as a single, primary task) with Sternberg task performance under various dual task conditions created by requiring the subjects to perform MFK or flight control tasks simultaneously with the Sternberg. Thus, Sternberg task *performance provided a standard for assessing the impact of various primary tasks in terms of reserve* information processing capacity.

PROCEDURE

TRAINING

Prior to the experiment proper each subject was trained on all three tasks: flight control, MFK and Sternberg. Training sessions lasted two hours with a ten minute break after one hour and were scheduled 2-4 times per week. Each subject was trained until task performance measures approached asymptotic levels. Each subject was trained for approximately 80 hours on the flight maneuvers. Training time per subject was about 50 hours on the MFK task. Training time for the Sternberg task was two hours per subject. In addition, a pilot study was run to assure that reaction times did not differ as a function of direction of throw or stick position for the thumb switch used for the Sternberg. This pilot study also provided an independent measure of "*simple*" reaction time for each subject. The stimulus to activate the thumb switch was a simple tone in the pilot study.

Subjects were trained on all seven flight maneuvers and on four levels of MFK difficulty using over 300 different keyboard tasks. The four levels of MFK difficulty were determined on the basis of the calculated information metric.

The tasks were divided into groups as follows:

Group	Information (Bits) Mean	Information (Bits) Range	Mean Number of Keyboard Actions
I	7	1-8	4
II	11	9-14	6
III	17	15-22	7
IV	26	23-35	10

During MFK training, the subjects were always informed as to which level of MFK difficulty they were performing and homogenity with respect to this level was maintained throughout a series of trials.

EXPERIMENTATION

General. There were six experimental sessions per subject. Each session was three to four hours in duration with ten minute breaks provided after each hour. The subject was always seated in the cockpit simulator with headset on except during the 10-minute rest periods.

The first three sessions were used to obtain baseline data on the Sternberg, flight control, and MFK tasks. The order in which the tasks occurred for a given subject was random. The next three sessions were used to obtain baseline data on performance under dual, or simultaneous, task conditions, i.e., (1) flight control with MFK, (2) Sternberg with flight control, and (3) Sternberg with MFK "implicit rehearsal." The term "implicit rehearsal" alludes to the fact that Sternberg test stimuli were presented only during intervals between the actual performance of keyboard tasks, that is, while the subject was awaiting instructions with regard to which particular keyboard task to perform at the given difficulty level. The subject was told, at the beginning of a series of trials, which level of difficulty (I, II, III or IV) the MFK tasks would be.

During the experiment a nominal cash incentive system was implemented to encourage performance. The amount of the incentive was based on relative standing in the group with respect to task performance criteria for each session. For the dual task condition the incentive value was weighted so as to emphasize priority for the flight control task. When the flight control task did not occur, incentives were weighted in favor of the MFK task over the Sternberg task.

Flight Control. There were 28 trials per subject — four for each of the seven maneuvers. At the beginning of a trial the subject was told which maneuver he was to fly including the flight parameter values to be maintained. Then he was allowed to "fly" the simulated aircraft until he was confident he was prepared to start the maneuver which he indicated by pulling a trigger switch on the control stick. At that point a 200 second trial began with automatic scoring and termination by the supporting computer program. There were 30-second intervals between trials.

MFK Task. Each subject was given 28 200-second trials as in the case of flight control. There were 7 trials for each of the 4 levels of MFK difficulty investigated. Thirty-second rest intervals separated trials. Four different MFK tasks of the given difficulty level were performed during each trial period. Thus, the subjects were tested on 28 different MFK tasks at each difficulty level. The subject received prerecorded instructions via his earphones concerning the task he was to perform. The instructions were followed by a tone which was the signal to start the MFK task. The subject depressed a "stop" button on the left side panel to the right and ahead of the throttle, to indicate he had completed the MFK task. Task time and key actions taken were recorded automatically. In addition, the experimenter monitored the duplicate displays at his station to ascertain the correctness of subject actions on the MFK.

Reserve Capacity Test. Again, the test period for each subject was divided into 28 200-second trials with 30-second breaks between trials. The test stimuli were recorded on cassette tapes and presented auditorially through the headset. Sternberg test stimuli were not presented during trial intervals corresponding generally to times during which MFK switch actions were actually performed during the MFK baseline session (described above) and MFK dual task conditions (below). The number of Sternberg test stimuli per 200-second trial ranged from 20 to 30. The average number of responses obtained per subject at each memory load level was 185. Response times, errors and time-outs were recorded automatically.

Flight Control with MFK. This session was identical to the flight control single, or baseline, task condition except as follows. Thirty seconds after the subject's signal that he was ready for scoring of the flight maneuver to start, the recorded instructions for the first MFK task were presented. Thus, the flight control and MFK single task scenarios were "overlaid" so that each subject had to divide his attention between them throughout the standard 28 200-second trial periods. The subjects were instructed to give first priority to flight control. Subjects also were informed that they would receive credit for MFK performance in the competition for incentive bonuses only if their performance on

flight control was equal to or better than the highest level achieved during training. (No subject failed to meet that requirement.)

Flight Control with Reserve Capacity Test. The flight control and Sternberg single task scenarios were combined to produce a divided-attention task situation comprised of 28 200-second trials per subject. Approximately 72 Sternberg responses were obtained per subject for each memory load level under each flight control difficulty level.

MFK with Sternberg Task. Again the corresponding single task scenarios were essentially "overlaid" with priority given to MFK tasks. Sternberg test responses did not actually conflict with MFK psychomotor behavior, however, since the Sternberg stimuli were presented only during the intervals while the subject was awaiting the instruction identifying the specific MFK to be performed. This was consistent with the interest in determining whether the Sternberg task would be sensitive to any cognitive loading ("implicit rehearsal") associated with maintaining in memory the "program routines" for the various MFK tasks. (It should be noted that all subjects acquired the ability to very rapidly perform the MFK tasks without taking time to read pushbutton labels as they were presented during the course of the multiple "indenture" tasks. Thus, the skill acquired is similar to that of the "touch typist.") An average of 72 Sternberg responses were obtained per subject at each memory load level for each MFK difficulty level.

RESULTS[1]

SINGLE TASK CONDITIONS

Flight Control Performance. A simple analysis of variance for a repeated-measures design was applied to the weighted score combinations obtained for the flight control single task condition. The effect of maneuver type was statistically significant ($p < .05$, $F= 12.53$, $df= 6, 18$). Tukey's test for honestly significant differences (hsd) between pairs of means was also applied (Winer, 1962, p. 87). In summary, the results provided the basis for dealing with the flight control data in subsequent analyses and comparisons in terms of two levels of task difficulty, "easy" and "difficult," as indicated in the preceding discussion of independent variables. Means and standard deviations of performance scores for the various maneuvers are shown in Table 3.

Multifunction Keyboard Task Performance. In order to obtain normality of distributions, MFK task times were subjected to reciprocal transformation prior to performing the analysis of variance. The effect of task difficulty proved significant statistically ($p < .001$, $F= 254.0$, $df= 3,9$). The Tukey hsd test showed that the mean for each task difficulty level differed from every other mean. Means and standard deviations are presented in Table 4. The average rate of information transmission via the MFK system varied from 1.8 bits/sec. to 2.6 bits/sec. across the four levels of MFK task difficulty. The switch action rate was slightly greater than 1 per second on the average.

Reserve Capacity Test Performance. Preliminary analysis of data for the Sternberg task showed no statistically significant differences between reaction times as a function of whether the test stimulus was from the positive or negative set. Hence, data from the two types of test stimuli were pooled for analyses. Examination of errors, i.e., indicating that the probe stimulus was a member of a set (positive or negative) when it was not, showed less than 5 percent errors for the first three memory load levels for the baseline Sternberg condition. For the 6-item memory load, responses were in error approximately 15 percent of the time. Although variations in error rate are undesirable when times for different tasks are to be treated as comparable, data from the 6-item set were included for the purpose of determining the line of best fit. Summary data for the Sternberg baseline condition are presented in Table 5.

The method of least squares was used to fit a straight line to the Sternberg data. The result is reflected by the following regression equation with constants given in milliseconds:

$$RT= 549+ 118\,(H_c)$$

It is significant to note that the average thumb switch activation time, determined from the pilot study using a tone as the stimulus, was 533 milliseconds. This accounts for all but 16 milliseconds of the intercept value of the fitted equation and is regarded as an independent check of its accuracy. Since omission of the last point (memory load of six items) would have resulted in a slightly smaller slope but greater intercept value (approximately 600 msc), its inclusion in the regression equation determination appears to be defensible despite the increased error rate at that level.

DUAL TASK CONDITIONS

Flight Control with MFK Task.
Although mean flight control error was greater when the flight control task was combined with MFK tasks, the differences were not statistically significant. The data are summarized in Table 6.

Similarly, MFK task times generally increased under dual task conditions although the differences were not statistically significant. Mean MFK times are presented in Table 7.

Flight Control with Sternberg Task. Flight control error scores were virtually identical for flight control alone as compared to flight control with the Sternberg task. Summary means are shown in Table 8.

MFK with Reserve Capacity Test. The Sternberg task had no statistically significant impact on MFK task times. Mean time scores and standard deviations (SD) for single and dual task conditions are shown in Table 9 for each of the four MFK levels.

[1]Preliminary analysis of data from this experiment was documented in a memorandum by Berisford (1975).

TABLE 3

FLIGHT CONTROL PERFORMANCE: SINGLE TASK CONDITION

	Weighted Error	
	Mean	**SD**
Easy Flight Control	1.09	.17
Difficult Flight Control	5.11	1.51

TABLE 4

MFK PERFORMANCE: SINGLE TASK CONDITION

MFK Difficulty	Task Time (Sec.) Mean	SD
I	3.97	.32
II	5.95	.53
III	7.43	.68
IV	9.87	.83

TABLE 5

STERNBERG TASK BASELINE PERFORMANCE

H_c (bits)	Response Time (Msc.) Mean	SD
1.00	680	98
1.50	718	67
2.00	764	88
2.31	842	90

TABLE 6

WEIGHTED ERROR SCORES FOR FLIGHT CONTROL FOR FLIGHT CONTROL ALONE AND WITH MFK

	Condition	
	Single Task	**With MFK**
Easy Flight Control	1.09	1.92
Difficult Flight Control	5.11	5.85

TABLE 7

MFK TASK TIMES (SECS.) FOR MFK ALONE AND WITH FLIGHT CONTROL

Condition	Single Task		With Flight Control	
	Mean	**SD**	**Mean**	**SD**
MFK-7 Bits	3.97	.32	4.63	1.78
MFK-11 Bits	5.95	.53	7.36	2.67
MFK-17 Bits	7.43	.68	9.65	3.35
MFK-26 Bits	9.87	.83	12.49	3.89

Reserve Capacity Test Performance Under Dual Task Conditions. A check of errors and "time outs" (failure to respond within two seconds) showed significant increases at the 6-item ($H_c = 2.31$) memory set level. A trend toward more time outs also appeared with increases in primary task loads for dual task conditions at other memory load levels. See Table 10 (Note that there were, on the average, 740 trials (185 per subject) per memory load level for the baseline condition and 290 (72 per subject) for each dual task condition.)

Percentage of time outs (failure to respond within 2 seconds) were as shown in Table 11.

Welford (1960) has admonished, with regard to the application of Hick's law, that times for different tasks should be regarded as comparable only if errors are held constant. However, examination of the plots of means showed that elimination of the H = 2.31 data points, where the greatest discrepancy occurred, would have little effect on *relative* differences among the task conditions of interest, i.e., elimination of the final data point would tend to increase intercept values and decrease slopes for *all* task conditions. Therefore, all four data points were included in the analyses.

The method of least squares was used to fit linear equations to Sternberg response time data for each dual task condition. This permits comparison of intercept and slope values with those obtained for the Sternberg task baseline condition, for the purpose of localizing divided attention effects within the four stage information processing model.

Preliminary analysis showed no significant differences between levels of MFK task difficulty in terms of slopes and intercepts. Hence, a single regression equation was derived for the combined MFK data. Equations for the resultant three dual task conditions and one baseline condition are as follows:

Sternberg Baseline	$RT = 549 + 118\,(H_c)$
Sternberg with MFK "Rehearsal"	$RT = 617 + 118\,(H_c)$
Sternberg with Easy Flight Control	$RT = 694 + 98\,(H_c)$
Sternberg with Difficult Flight Control	$RT = 885 + 31\,(H_c)$

The above four regression functions are represented graphically in Figure 10.

F-tests (Snedecor and Cockran, 1967) indicate that (1) slopes and intercepts for the flight control conditions differ significantly from those for the baseline condition, and (2) the intercept value varies significantly between the baseline and MFK implicit rehearsal condition.

To illustrate the trend within the MFK conditions separate regression equations were fitted to the Sternberg data for "easy" (7- and 11-bit levels combined) and "difficult" (17- and 26-bit levels combined) MFK conditions. These equations are shown below:

"Easy" MFK Rehearsal: $RT = 605 + 117\,(H_c)$

"Difficult" MFK Rehearsal: $RT = 636 + 115\,(H_c)$

DISCUSSION

LOCUS OF DIVIDED ATTENTION EFFECTS

Interpreted in the traditional manner, the preceding results indicate that the effect of the MFK "implicit rehearsal" loading is in the input or output stage of information processing only. Following the empirical evidence and logic of Briggs et al (1972), the effect is probably in the input stage. The difference in intercept values amounts to a 12% average increase in input-output time attributable to MFK "implicit rehearsal."

Active flight control, on the other hand, appears to impact both input and central processing as evidenced by differences from baseline in both intercept and slope values for the regression equation. Moreover, there is an increase in input-output time (28% and 55% for easy and difficult flight control, respectively) and an increase in central processing rate. The central processing rate for the baseline condition is 8.47 bits/sec. as compared to 10.20 bits/sec. and 32.26 bits/sec. for the easy and difficult flight control conditions respectively. This increased efficiency in central processing under the dual task condition is consistent with results obtained by Lyons and Briggs (Briggs et al., 1972). It was attributed to the subject's conducting fewer or less complete tests of the probe stimulus under the greater loading condition. This apparent switch in mode of operation in the central processing stage may prove to be a valuable aid to identification of significant increase in workload.

INFORMATION TRANSMISSION EFFECTS

The variations in Sternberg task response accuracy, noted in the results section (i.e., the increased error rates and time outs at higher load levels), suggested the appropriateness of further information analyses, the most obvious being calculation of the average amount of information transmitted (which would reflect *all* the data including erroneous responses and time outs, for each principal experimental condition). These values for the baseline and two levels of each dual task condition are presented in Table 12.

TABLE 12

AVERAGE INFORMATION TRANSMITTED (H_t) in BITS FOR STERNBERG TASK

	H_c			
Condition	*1.00*	*1.50*	*2.00*	*2.32*
Baseline	.85	.85	.88	.41
Easy MFK	.86	.85	.94	.42
Difficult MFK	.84	.88	.86	.32
Easy Flight Control	.82	.77	.79	.27
Difficult Flight Control	.72	.72	.79	.26

TABLE 13

INFORMATION TRANSMISSION RATES (H_t) (BITS/SEC.)
ON STERNBERG TASK

		H_c			
Condition	*1.00*	*1.50*	*2.00*	*2.31*	*MEAN*
Baseline	1.25	1.19	1.15	.49	1.02
Easy MFK	1.18	1.10	1.13	.48	.97
Difficult MFK	1.13	1.06	1.04	.35	.90
Easy Flight Control	1.02	.93	.90	.29	.79
Difficult Flight Control	.81	.80	.87	.28	.69

The H_t values in Table 12 were used in combination with mean *total* response times for each experimental condition to calculate the rates of information transmission (Table 13). Note the consistency of the information transmission rate in differentiating between primary task conditions across H_c levels. Conversion of the Sternberg task information transmission rates for each primary task condition to percentages of the baseline at each H_c level, produced the values in Table 14. Thus, on the average, easy MFK "implicit rehearsal" reduces information transmission reserve capacity by four percent; difficult inplicit rehearsal, by 15 percent; easy flight control, by 26 percent; and difficult flight control, by 34 percent.

From the means column in Table 13 we see that easy MFK "rehearsal" may be inferred to be equivalent to an information transmission rate of .05 bits/sec., difficult MFK rehearsal, .12 bits/sec., easy flight control, .23 bits/sec., and difficult flight control, .33 bits/sect. (The foregoing values simply represent the difference between average baseline performance and average performance under the various dual task conditions.)

CENTRAL PROCESSING EFFECTIVENESS

The values in *Table 12* were *used to obtain estimates* of the amount of central processing uncertainty effectively reduced via the subjects under each condition. Since perfect transmission was equal to 1.0 bit in every instance, the information transmitted values are equivalent to percentages; hence, they were simply multiplied by H_c (central processing uncertainty) to obtain the set of values in Table 15. (It is assumed that response errors are due to imperfect central processing.)

TABLE 14

INFORMATION TRANSMISSION RATES AS PERCENT OF STERNBERG BASELINE PERFORMANCE

Condition	H_c *1.00*	*1.50*	*2.00*	*2.31*	*MEAN*
Easy MFK	94	92	98	98	96
Difficult MFK	90	89	90	71	85
Easy Flight Control	82	78	78	59	74
Difficult Flight Control	65	67	76	57	66

TABLE 15

AMOUNT OF UNCERTAINTY EFFECTIVELY REDUCED

Condition	Average Amount of Uncertainty Effectively Reduced (Bits)			
	H_c *1.00*	*1.50*	*2.00*	*2.31*
Baseline	.85	1.28	1.76	.95
Easy MFK	.86	1.28	1.88	.97
Difficult MFK	.84	1.32	1.72	.74
Easy Flight Control	.82	1.16	1.58	.62
Difficult Flight Control	.72	1.08	1.58	.60

The values in Table 15 were converted to "effective" uncertainty reduction *rates*, i.e., central processing rates, by taking the difference between the average "simple" reaction time obtained for the subjects and the average response time as the central processing time for each Sternberg condition. The rates so derived are shown in Table 16.

A graphical presentation of the data in Table 16 is shown in Figure 11. Note the marked shift from *increasing efficiency as* H_c *exceeded 2.00 bits under all conditions.* "Overload" apparently occurs somewhere between 2.00 and 2.31 bits of H_c.

If baseline performance on the Sternberg task is taken as the standard index of central processing capability, the difference in rate for each dual task condition may be treated as a percentage of loss in reserve central processing capacity attributable to the primary task as shown in Figure 12.

Disregarding the $H_c = 2.31$ level, which apparently created overload situations in all instances including baseline, the average absolute difference in uncertainty reduction rates suggests that the various primary tasks place demands on the subjects equivalent to the following H_c reduction rates:

	H_c EQUIVALENT
Easy MFK	1.49 bits/sec.
Difficult MFK	2.07 bits/sec.
Easy Flight Control	3.00 bits/sec.
Difficult Flight Control	3.74 bits/sec.

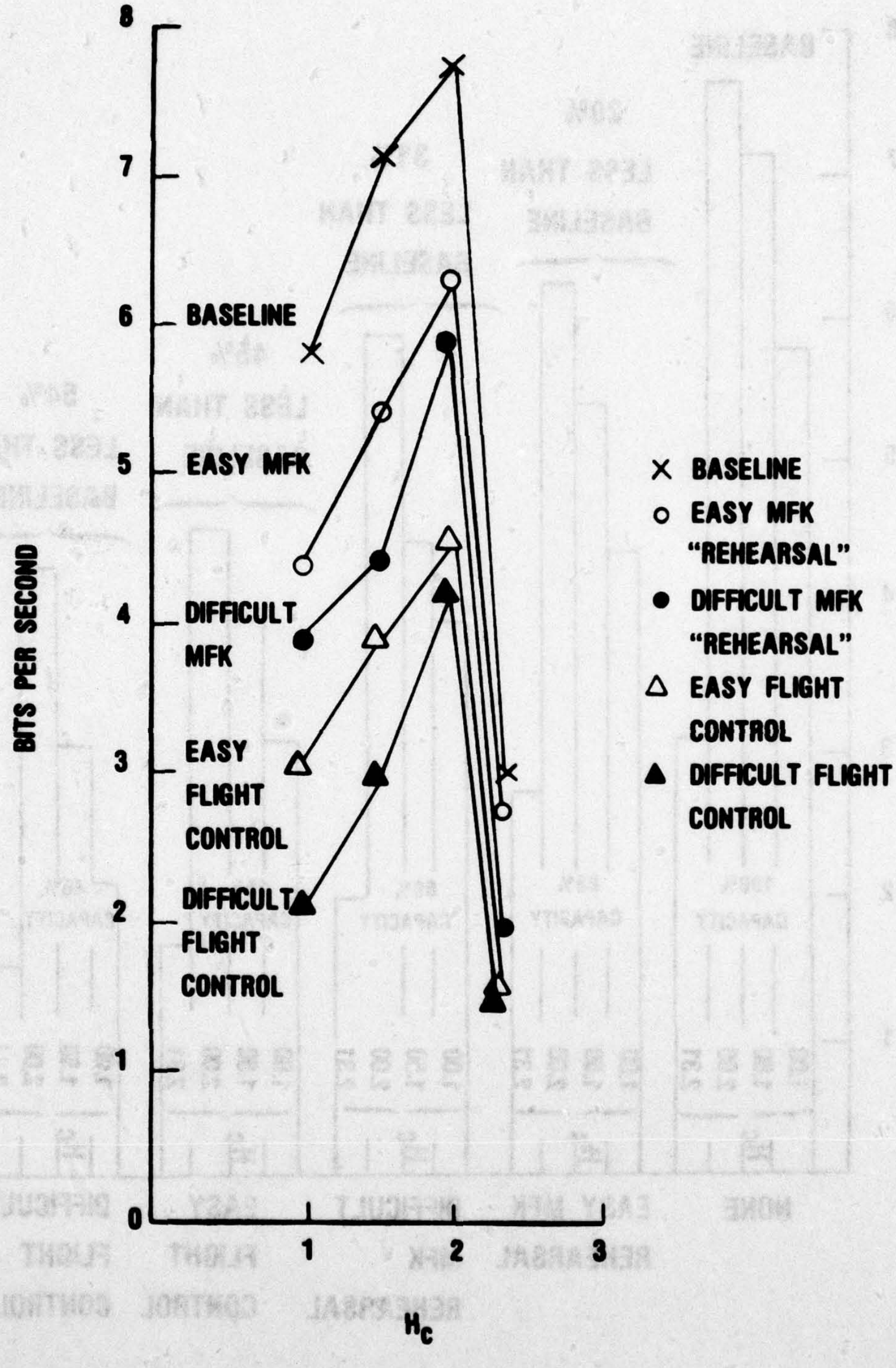


Figure 11. Average rates of effective information reduction on Sternberg task as a function of primary task condition.

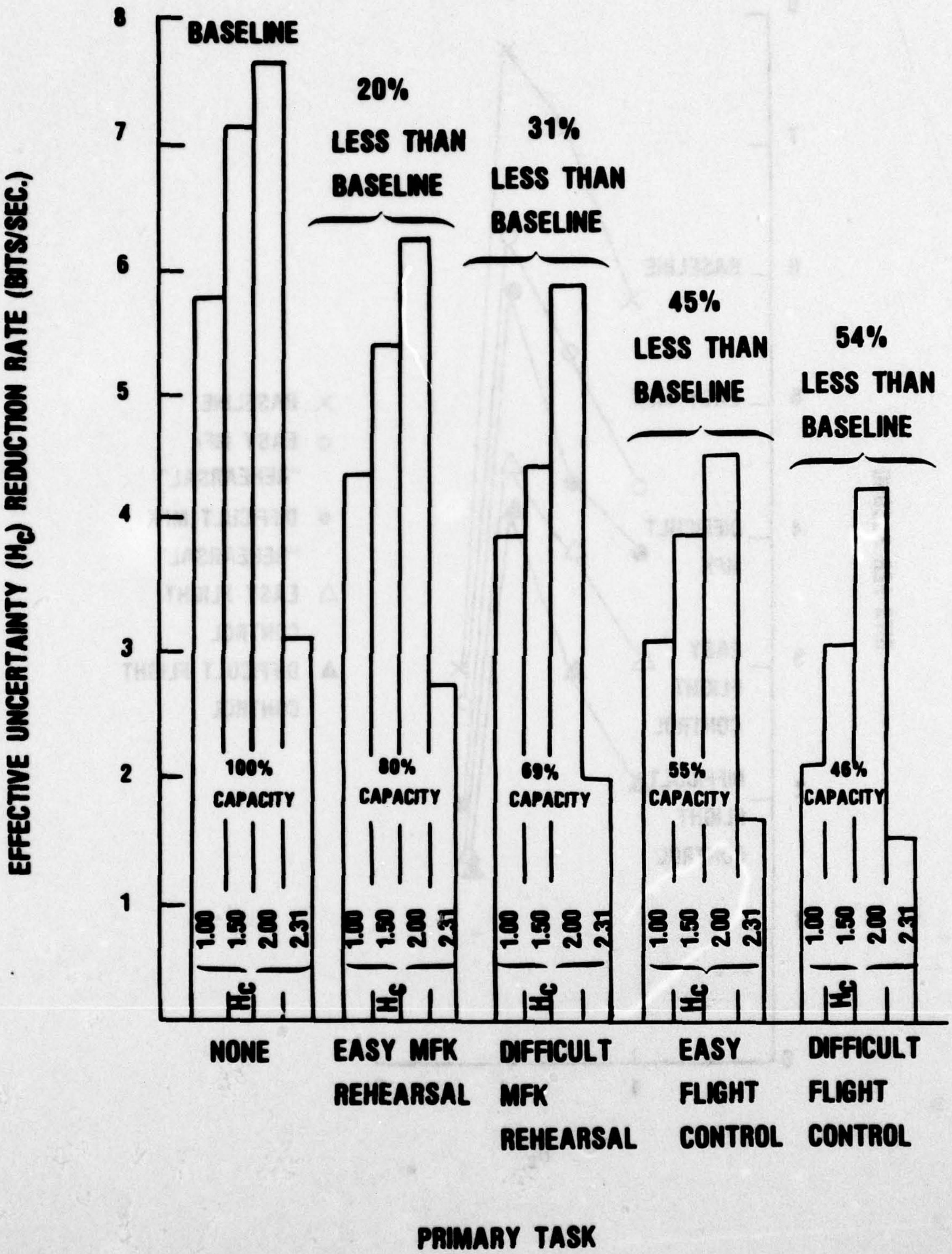


Figure 12. Average effective information reduction rates and percent remaining reserve capacity.

TABLE 16

EFFECTIVE UNCERTAINTY REDUCTION RATES (BITS/SEC.)

Condition	H_c *1.00*	*1.50*	*2.00*	*2.31*
Baseline	5.78	7.11	7.62	3.07
Easy MFK	4.37	5.40	6.29	2.76
Difficult MFK	3.94	4.47	5.89	1.97
Easy Flight Control	3.07	3.91	4.53	1.56
Difficult Flight Control	2.11	2.98	4.21	1.49

It is interesting to note that the values reflective of the implicit rehearsal impact on information reduction reserve capacity are identical in proportion to the corresponding information transmission rates for actual performance of the associated MFK tasks under the dual task condition (MFK plus Sternberg task), thus:

$$\frac{1.49 \text{ bits/sec.}}{1.72 \text{ bits/sec.}} = .87 \text{ for easy MFK,}$$

$$\text{and } \frac{2.07 \text{ bits/sec.}}{2.37 \text{ bits/sec.}} = .87 \text{ for difficult MKF}$$

Assuming that the relationship between response time and *effective* uncertainty reduction established by the Sternberg baseline data for the first three memory load (H_c) levels is a valid reflection of central processing capacity, the associated regression equation can be used to make inferences about the amount of effective uncertainty reduction involved in performance of MFK *implicit* rehearsal and the two levels of flight control task tested. The best fitting linear regression equation for those data is:

$RT = 598 + 93\,(H_{ce})$ where H_{ce} = uncertainty effectively reduced in bits.

By inserting Sternberg response times (Figure 10) from the appropriate dual task conditions into the preceding equation, the following estimates of H_{ce} were obtained:

Primary Task	*1.00*	H_c *1.50*	*2.00*
MFK "Rehearsal"	1.56	2.16	2.48
Easy Flight Control	2.18	2.49	3.05
Difficult Flight Control	3.18	3.19	3.34

Of course, the values in the preceding table include estimates of the central processing load for both the primary task and the secondary Sternberg task. Therefore, subtraction of the observed effective Sternberg *baseline* uncertainty reduction values (Table 15) for each H_c provides desired estimates of primary task load in terms of the H_{ce} metric as shown below:

Primary Task	*1.00*	H_c *1.50*	*2.00*	*MEAN*
MFK "Rehearsal"	.70	.88	.72	.77
Easy Flight Control	1.33	1.21	1.29	1.28
Difficult Flight Control	2.33	1.91	1.58	1.94

Thus, the marginal means are estimates of the central processing loads being processed in accomplishing the primary tasks indicated at the level of performance measured in the experiment. The mean value for difficult flight control may be suspect due to the rather significant decline in value across the three M-set levels which may be attributable to the previously hypothesized change in method of memory search on the Sternberg task for this condition. The larger value (2.33 bits) at H = 1.00, therefore, may be a better estimate than the mean, in this case.

Obviously, the estimates presented in the last three tables are tenuous because of the considerable amount of conjecture involved in deriving them. Hopefully, effective methods of obtaining more *direct* measures of the information processing involved in the primary tasks can be obtained in the near future so that the results may be used to evaluate the reliability of the Sternberg performance metrics as indirect indices of processing loads for primary tasks less susceptible to such quantification *directly*.

Ultimately, metrics of the type used in this study may be combined with a generic set of basic processes to facilitate workload quantification and allocation at the functions and task analysis stage of system development. For example, Briggs et al (1972) have derived a tentative set of such functions and information handling rates for the human information processing system and Teichner (1974) is currently developing a similar system and supportive data base.

DESIGN IMPLICATIONS IN GENERAL

While the products of research such as this should ultimately benefit all phases of man-machine system development from conceptualization to test and evaluation, they are presently oriented toward needs of designers, who, based on appraisals of the possible contingencies, attempt to minimize the frequency, extent and seriousness of work overload situations. At the present time system designers cannot rigorously assess "mental" workload, or potential mental workload, since there is no standard metric for adequately defining or measuring it. It follows, of course, that there is no criterion by which one can decide and demonstrate that workload problems do not exist. Hence, work overloads may only be revealed through operator or crew performance deficiencies under high-stress operational conditions which may result in mission failure, loss of life and, perhaps, loss of the system. It is true that the latter events are usually low probability ones, but they may be *very* costly.

In the development laboratories, alternative proposed designs or arrangements, or alternative procedures, may be compared on the basis of speed, accuracy, or errors. However, operationally significant differences may not be revealed simply because the subjects are able to, and do, muster their resources, "try harder" and thus compensate for what would otherwise be real differences. If instead of, or in addition to, the typical speed/accuracy measurements, measures of depletion of reserve workload capacity can be obtained, they may provide designers with more meaningful, accurate, and defensible information concerning which alternative is the more promising and hence the prime candidate for further development and for use in operational systems. Also, such metrics could be incorporated into larger man-machine system models and used to predict system/mission effectiveness.

IMPLICATIONS FOR DIGITAL AVIONICS

With regard to the design issue addressed by this study, it appears that the multifunction switch concept places demands on the operator which may inappropriately detract from the true value of digital processing capabilities in avionics systems. This is not to say that the concept is necessarily inefficient. It is simply that it involves the concentration of multiple sources of uncertainty, normally distributed among the various dedicated instrument control/display interfaces, at a single interface. Moreover, uncertainty which is normally removed via separate controls and displays for each subsystem/function has to be eliminated via keyboard actions on each occasion that the operator interacts with the multifunction system. To illustrate, changing from one channel to another on the main UHF set, the task depicted in Figures 3-6, is accomplished on a conventional dedicated aircraft communications system by turning a rotary selector switch with 20 detented positions. This may be regarded as a 4.32 bit ($Log_2 20$) task which may be accomplished by a single rotary movement. The same task accomplished on the MFK, beginning at indenture level one, is a 13.64 bit task requiring five push button actions (for a two-digit channel designation). An empirical test, using four subjects and an F-100 aircraft, showed the average time (four trials per subject) to change UHF channels was 3.2 seconds. The same four subjects took an average of 7.1 seconds to perform the task on the MFK system. (Subjects actually used in the MFK experiment performed somewhat faster averaging about one switch action per second).

Thus, the MFK method took about twice as long as the conventional one but involved five times as many discrete actions and over three times as much information or uncertainty reduction. (Of course, any uncertainty the operator may have with regard to which *dedicated* control/display interface to use is neglected in this analysis).

Thus, while the digitally based MFK system is relatively efficient in terms of action and information transmission rates, the tasks are generally more complex and take longer than corresponding ones for dedicated instruments. While results of this experiment showed that the MFK tasks could be performed in combination with flight control without statistically significant effects on flight control error scores, error was almost twice as great on the average for the straight and level maneuvers and failure to obtain statistical significance is probably due to the small sample size (four subjects). Of course, the practical significance of flight control error is a function of the flight situation and the probability of a pilot finding it essential to perform MFK tasks simultaneously with critical flight control tasks also must be considered. Nevertheless, the highly consistent trend, across all Sternberg task memory loads, indicative of reduced reserve cognitive capacity as a function of simply anticipating and maintaining a readiness to perform MFK tasks, suggests the importance of this consideration. Critical decision-making situations requiring the pilot to make the correct judgement and a corresponding control action with split-second timing may be relatively rare events during tactical missions, but failure to do so may contribute to mission failure or loss of a very expensive weapon system including the pilot. Hence, care should be taken to assure that the digital processing capabilities, which potentially afford very significant advantages in terms of overall system capabilities, are not poorly applied or perhaps lost at the man/machine interface.

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